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Aquatic Vegetation Restoration in Cooper Lake, Texas: A Case Study

Gary Owen Dick, R. Michael Smart, and JoEtta K. Smith

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Environmental Laboratory

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Final report

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ABSTRACT: Aquatic plants improve water clarity and quality (James and Barko 1990) and reduce rates of shoreline erosion and sediment resuspension (James and Barko 1995). Further, aquatic plants provide valuable fish and wildlife habitat (Dibble et al. 1996) and serve as a food source for waterfowl and aquatic mammals. Native aquatic plants also help prevent spread of nuisance exotic plants (Smart et al. 1994), a role that has been of primary interest to the Aquatic Plant Control Research Program (APCRP).

Because the research on aquatic plant establishment conducted under the APCRP represented the current "state of the art" (Smart et al. 1996), the Texas Parks and Wildlife Department solicited our involvement in the development of techniques (TPWD Aquatic Habitat Enhancement Initiative) for establishing aquatic plants for fish habitat improvement in Texas reservoirs. Because there is still much to learn regarding establishment of beneficial native plants, we elected to participate in this project and to incorporate testing and data collection in an attempt to further advance the science. This report documents the restoration project and describes what we learned in the process.

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 33084. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. Mr. Robert C. Gunkel, Jr., EL, was Manager, APCRP. Program Monitor during this investigation was Mr. Timothy R. Toplisek, ERDC.

Principal Investigator for this study was Dr. R. Michael Smart, Lewisville Aquatic Ecosystem Research Facility, Ecosystem Processes and Effects Branch (EPEB), Ecology and Environmental Engineering Division (EEED), EL. The report was prepared by Dr. Smart and Dr. Gary Owen Dick and Ms. JoEtta K. Smith, both assigned to EEED under an Intergovernmental Personnel Act Agreement with the Institute of Applied Science, University of North Texas, Denton, TX. The report was reviewed by Ms. Dian Smith (EEED), and Ms. Chetta Owens, AScI.

This investigation was performed under the general supervision of Dr. Elizabeth Fleming, Acting Director, EL; Dr. Dave Tazik, Chief, EEED; and Dr. Al Cofrancesco, Chief, Aquatic Ecology and Invasive Species Branch.

COL James R. Rowan, EN, was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Overview

Introduction

Aquatic plants improve water clarity and quality (James and Barko 1990) and reduce rates of shoreline erosion and sediment resuspension (James and Barko 1995). Further, aquatic plants provide valuable fish and wildlife habitat (Dibble et al. 1996) and serve as a food source for waterfowl and aquatic mammals. Native aquatic plants also help prevent spread of nuisance exotic plants (Smart et al. 1994), a role that has been of primary interest to the Aquatic Plant Control Research Program (APCRP).

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Background

Most water bodies in the state of Texas are manmade impoundments, generally constructed for flood control and water supply. Secondary uses include recreational boating and fishing. TPWD is charged with management of fisheries and wildlife in many of these water bodies, and over the years it has utilized numerous techniques in manipulating fish populations to improve the quality of existing fisheries (Webb 1997, pers. comm.). While stocking fish has proven beneficial in terms of establishing fisheries, and harvest limits help maintain an established fishery, the current demand for quality fisheries cannot be met by stocking and slot limits alone. TPWD recognizes that fishery habitat in many Texas reservoirs has declined as flooded terrestrial structures have disappeared over time. For this reason, TPWD has made efforts to enhance habitat by addition of structure (generally brush and manufactured structures), although these usually prove to be short-lived. The most productive established reservoirs in Texas often support aquatic plants, and the sustainable structure offered by these plants appears to play a major role in fishery productivity (Durocher et al. 1984). Unfortunately, most Texas reservoirs support little or no aquatic vegetation, and

those that do are frequently dominated by exotic nuisance species. As part of its Aquatic Habitat Enhancement Initiative, TPWD funded a multiyear experimental project investigating methods for establishing native aquatic plants in several reservoirs around the state. Cooper Lake was one of these reservoirs.

Cooper Lake is a relatively new and moderately fluctuating northeast Texas reservoir (Figure 1). Impounded on the South Sulphur River in 1991, the reservoir encompasses approximately 9,200 hectares (22,740 acres) at full pool (134 m (440 ft mean sea level (msl))). Water is moderately alkaline, with pH ranging from 7.4 to 7.8. Turbidity is moderate, with Secchi visibility generally recorded between 30 and 60 cm (1 to 2 ft) deep. Maximum depth at full pool is 23.7 m (79 ft). The shoreline is composed primarily of clays and sand. Historically, submersed aquatic vegetation has been limited to a few small infestations of hydrilla, which have not persisted. Emergent vegetation reported from the lake includes lance-leaf water willow (Justicia ovata) and maidencane (Panicum hemitomon). Fishing quality is good. TPWD biologists report common carp and semiaquatic turtles as potential herbivores (Storey 1997, pers. comm.).

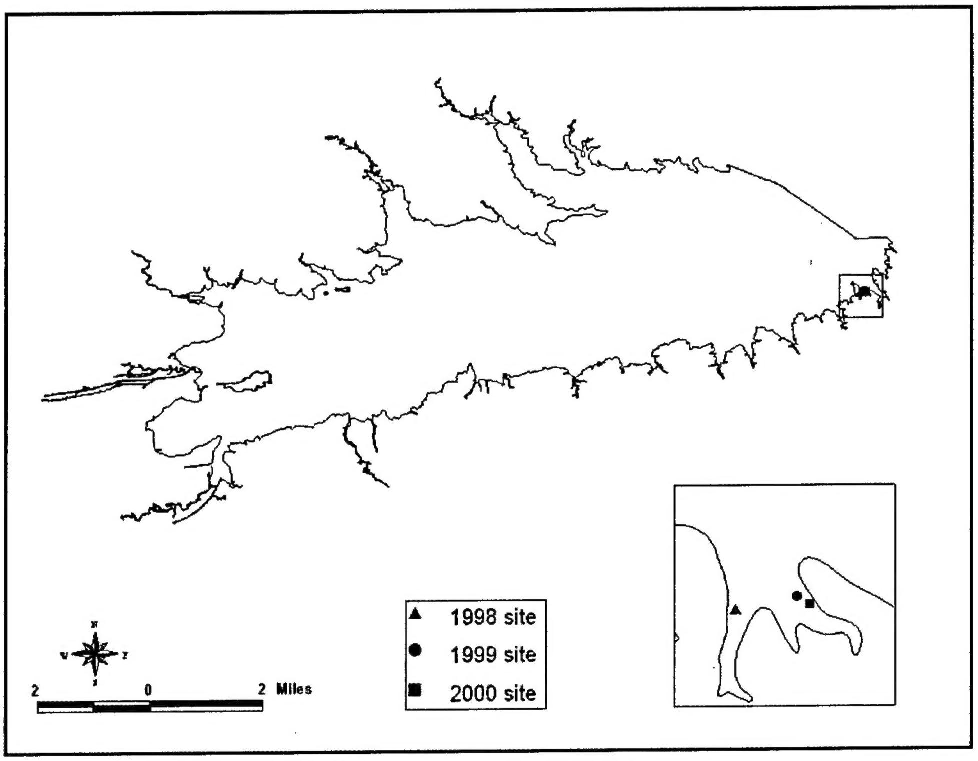

Figure 1. Aquatic vegetation restoration sites at Cooper Lake, Texas

Aquatic vegetation does not establish easily in new reservoirs. Most species are not found in the immediate vicinity of newly impounded reservoirs; and therefore, no propagules are readily available for their establishment (Smart et al. 1996). Those few propagules that may be brought in (by waterfowl, boaters, etc.) are often consumed by grazers such as carp and turtles (Dick et al. 1995), which quickly become established even in the absence of vegetation. One approach to habitat manipulation in large reservoirs is establishment of native aquatic plant

founder colonies. Once founder colonies are established in a reservoir, they serve as sources of propagules otherwise not present in sufficient quantities for natural establishment of plants. By having seeds, fragments, and other reproductive structures present at appropriate times and in sufficient quantity, biotic and abiotic limitations may be overcome to allow spread to other parts of the reservoir (Smart and Dick 1999). The objectives of this project were to:

a. Determine native aquatic plant species suitable for Cooper Lake.

b. Develop techniques for establishing founder colonies in Cooper Lake.

(1) Ascertain the need for protection from herbivory.

(2) Develop methods for protection from herbivory.

(3) Develop methods for adapting to fluctuating water levels.

c. Monitor survival, growth, and spread from founder colonies in Cooper Lake.

Obstacles

Establishment of aquatic vegetation in Texas reservoirs generally meet with two major obstacles: (a) water level fluctuations; and (b) herbivory. Historically, water levels in Cooper Lake have exceeded conservation pool only during the winter, and generally rise 0.9 or 1.2 m (3 or 4 ft) each year (Figure 2). These spikes are short-lived, with floodwater release returning the lake to conservation pool within several weeks. Conversely, water levels in the lake have generally fallen below conservation pool by several feet in any given year. The duration of low-water conditions has been variable, with recovery dependent upon rainfall in the watershed. In 1999, during the course of this project, dam repair operations required intentional lowering and maintenance of the water level by 1.2 m (4 ft) for a period of 1 year. Water levels are important to aquatic plants for several reasons. Deep water during the critical dormancy-breaking period (spring) for aquatic plants may reduce light to inhibit successful sprouting and survival of species planted too deeply relative to conservation pool (Barko et al. 1982). Longer periods of high water may deprive sprouted plants of light (and oxygen, in some emergent species), resulting in mortality. On the other hand, low-water conditions may expose plants to desiccation. While most species of aquatic plants exploit biological strategies (such as production of desiccation-resistant seeds and tubers) to overcome low-water conditions, newly establishing plants are highly susceptible and may not recover from these events.

According to TPWD, biologists charged with managing the lake's fishery, common carp (Cyprinus carpio) were known to be abundant in the lake, and semiaquatic turtles had been observed. Both of these animals are opportunistic omnivores, readily make use of aquatic plants as a food source, and have been detrimental in other aquatic plant establishment projects (Smart et al. 1996; Doyle et al. 1997). Other animals reported from the lake, including beavers and waterfowl, also damage newly installed aquatic plants in restoration projects.

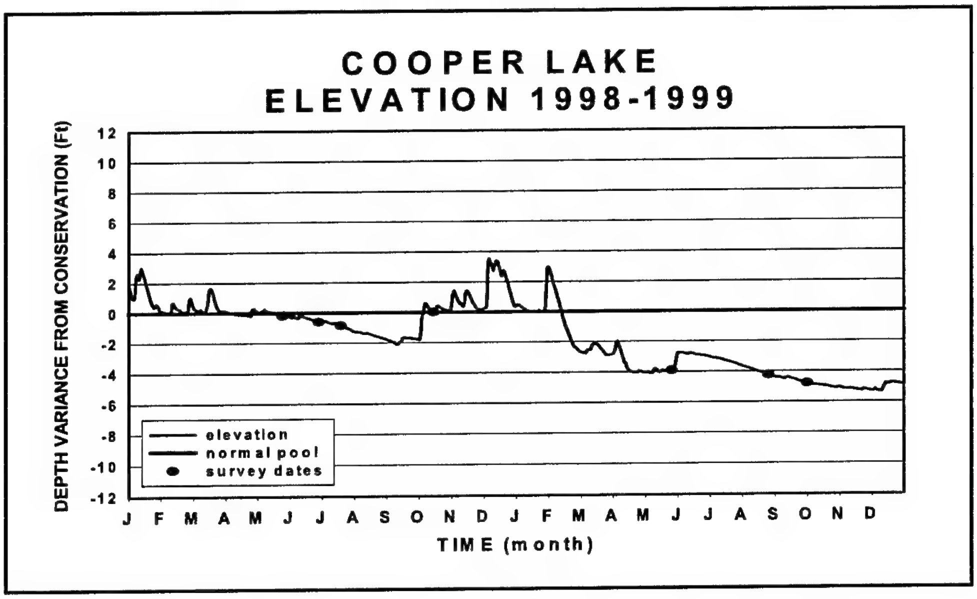

Figure 2. Water levels reported from Cooper Lake over a 2-year period

2 Approaches

This report covers aquatic plant founder colony establishment tests conducted from 1998 through 2000.

Site Selection

Two major criteria were used in selecting sites, including: (a) protection from wind and wave action; and (b) substrate texture. Sites that were shaded, developed, or occupied by existing aquatic vegetation were avoided. Protection from wind and wave action was generally found in coves on the predominantly windward (south) side of Cooper Lake. Waters associated with the coves were less turbid, affording greater light penetration and, therefore, greater potential growth of submersed plants. Additionally, reduced wave action lessened the probability of newly planted propagules from being washed out or covered by shifting sediments. Soft bottoms were chosen to enable rooting by vegetation. Substrates selected ranged from sandy to muddy, dependent upon depth and specific locations within a site. Hard-packed clay and gravelly or rocky bottoms were avoided.

Species Suitability

The question of which species of aquatic plants could survive in Cooper Lake was a primary focus of the tests, particularly in 1998 and 1999. Numerous species of aquatic plants were selected as test candidates, all of which had been documented as natives to the State of Texas (Diggs et al. 1999). Plant communities represented by high species diversities may be more successful in overcoming ecological disasters (such as excessively low-water levels), because different species have evolved different strategies for surviving environmental stresses (Brock 1988). Because water level fluctuations and herbivory particular to Cooper Lake (or any lake) were unpredictable, a variety of aquatic plants was chosen to ascertain each species' ability to survive short-term in the lake and each species' ability to recover from any environmental stresses that might occur during the project. Twenty-five species of aquatic plants were tested in 1998 (Table 1). An additional species (maidencane, Panicum hemitomon) was tested in 1999. Species deemed suitable for establishment were used in subsequent studies. Three general plant types (based upon growth forms) were tested during this phase:

Table 1
Aquatic Plant Species Tested in Cooper Lake 1998

Common Name	Scientific Name	Growth Form
American pondweed	*Potamogeton nodosus*	submersed
Illinois pondweed	*P. illinoensis*	submersed
Sago pondweed	*P. pectinatus*	submersed
Slender pondweed	*P. pusillus*	submersed
Southern naiad	*Najas guadalupensis*	submersed
Muskgrass	*Chara vulgaris*	submersed
Horned pondweed	*Zannichellia palustris*	submersed
Coontail	*Ceratophyllum demersum*	submersed
Wild celery	*Vallisneria americana*	submersed
Water stargrass	*Heteranthera dubia*	submersed
White water lily	*Nymphaea odorata*	floating-leaved
Spatterdock	*Nuphar luteum*	floating-leaved
Watershield	*Brasenia schreberi*	floating-leaved
Bulltongue	*Sagittaria graminea*	Emergent
Arrowhead	*S. latifolia*	Emergent
Tall burhead	*Echinodorus berteroi*	Emergent
Creeping burhead	*E. cordifolius*	Emergent
Pickerelweed	*Pontederia cordata*	Emergent
Water willow	*Justicia americana*	Emergent
Softstem bulrush	*Scirpus validus*	Emergent
Flatstem spikerush	*Eleocharis macrostachya*	Emergent
Squarestem spikerush	*E. quadrangulata*	Emergent
Slender spikerush	*E. acicularis*	Emergent
Water hyssop	*Bacopa monnieri*	Emergent
Water pepper	*Polygonum hydropiperoides*	Emergent

a. *Submersed forms* have leaves and stems found beneath or at the water surface and can colonize in 180-cm- (6-ft-) deep and deeper water. This growth form may be the most beneficial in terms of providing permanent underwater structure for fish habitat. Submersed plants exhibit variable tolerances to desiccation, but many produce propagules capable of withstanding such conditions.

b. *Floating-leaved forms* generally do not have subsurface leaves, and grow in 60- to 120-cm- (2- to 4-ft-) deep water. Stems provide underwater structure and floating leaves provide shade. Floating-leaved species exhibit variable tolerances to desiccation.

c. *Emergent forms* are typically found in water less than 60-cm- (2-ft-) deep and moist soils. While tolerant of periodic deeper water, these species do best as shoreline plants. In addition to shallow-water structure, emergent plants serve to stabilize the shoreline, reducing erosion and turbidity, improving water quality for the fishery. Many species are highly tolerant of desiccation.

Propagule Selection

For the most part, only well-established propagules were used in this study. Because native Texas aquatic plants grown in 10- or 15-cm- (4- or 6-in.-) diam nursery pots are not commercially available, all test plants were grown in culture facilities at the Lewisville Aquatic Ecosystem Research Facility (LAERF) in Lewisville, TX. Although other propagule types (such as tubers, fragments, and seeds) have been used in aquatic restoration projects with some success, results have been highly variable, whereby the use of potted plants has resulted in more consistent establishment of plant colonies. Therefore, potted plants offered the greatest chance of successful transplanting and subsequent growth for both short-term and long-term evaluations.

Herbivory

The need for protecting plants has proven to be a concern when attempting to establish plants in Texas reservoirs. Most Texas reservoirs support several grazing (omnivorous) species, most notably common carp and semiaquatic turtles. Additionally, nutria, muskrat, beaver, crayfish, and terrestrial grazers (during low-water events) may feed on newly installed plants. Although common carp and semiaquatic turtles occurred in Cooper Lake, densities and potential effects on newly establishing plant colonies were unknown. Therefore, several types of herbivore exclosures were tested to determine whether aquatic plant establishment required protection.

a. *Large-scale exclosures*. A shoreline fence (Figure 3) was constructed in 1998 from 5- × 10-cm (2- × 4-in., heretofore known as 2" × 4") welded-wire and t-posts along a suitable shoreline to a depth of about 1 m (3.5 ft). The shoreward side of this fence was not enclosed. Two additional shoreline fences were installed in 1999. A cove fence (Figure 3) was constructed in 1998 from 2" × 4" welded-wire and t-posts to enclose the mouth of a small cove. The perimeter shoreline behind this fence was not enclosed. A "fenceless" cove was selected to provide a control (no large-scale protection). Areas protected by large-scale exclosures (as well as the control site) were planted with submersed, floating-leaved, and emergent plants. Some plants were further protected with small-scale exclosures. A silt fence (modified shoreline fences, Figure 3) was constructed to a depth of 60 cm (2 ft). The welded-wire was lined with erosion control fabric to reduce wave action and turbidity, and the areas were seeded with pond sediments (from LAERF) containing seeds of southern naiad (*Najas guadalupensis*), American pondweed (*Potamogeton nodosus*), slender pondweed (*P. pusillus*) and horned pondweed (*Zannichellia palustris*) and spores of muskgrass (*Chara vulgaris*).

b. *Moderate-scale exclosures*. In 1998, six 2.4-m- (8-ft-) wide × 4.8-m- (16-ft-) long × 1.2-m- (4-ft-) high pens were constructed as an intermediate (by size) alternative to establishing selected submersed species (Figure 3). Two 2.4-m-wide × 2.4-m-long × 1.2-m-high (8-ft-wide

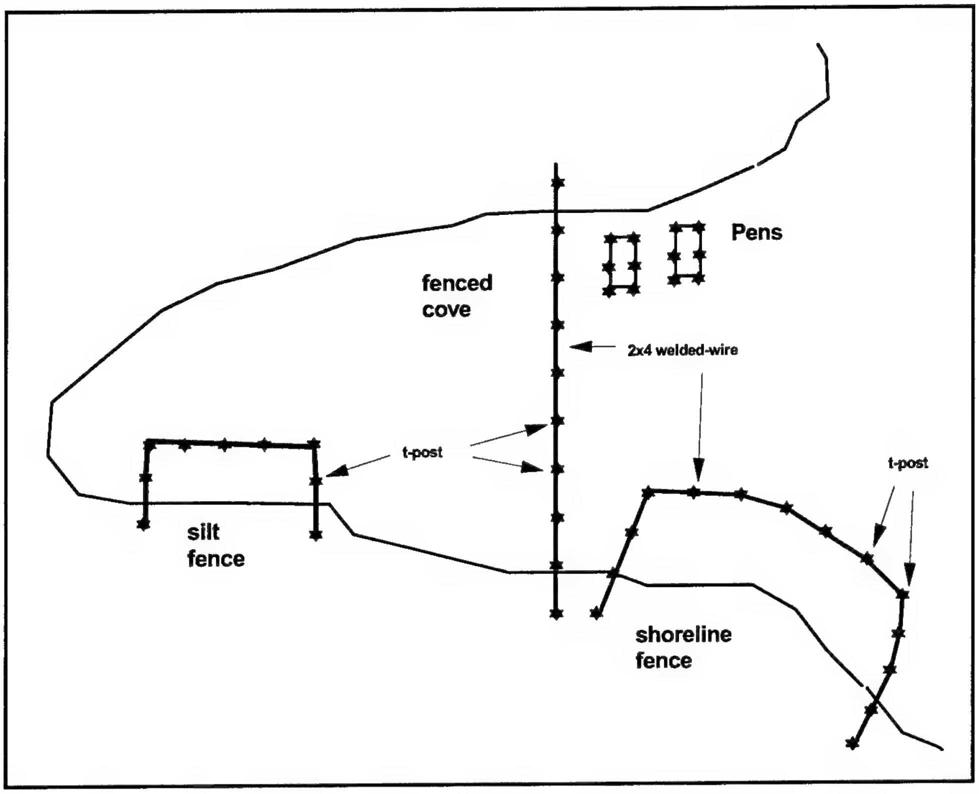

Figure 3. Large-scale herbivore exclusion devices deployed in Cooper Lake between 1998 and 2000

× 8-ft-wide × 4-ft-high) exclosures were constructed for establishment of American lotus in 1999.

c. *Small-scale exclosures.* In 1998, tomato cages (Figure 4) were constructed from 2" × 4" mesh welded-wire and anchored with short rods of rebar. These cages were used to ascertain an alternative method of protection as well as adding a second level of protection when incorporated into the large-scale protection design. In most cases, two plants of a single species were planted side by side (behind shoreline fence and cove fence, and at the no-fence sites). One of the two plants was then protected by a tomato cage. This test allowed us to assess the need for protection for each species in each reservoir. It also allowed evaluation by comparison with moderate- and large-scale protection device effectiveness. In 2000 and 2001, the general design of tomato cages was modified to produce greater diameter, taller cages for better overall protection. PVC-coated 2" × 4" mesh welded-wire was used to increase durability. Ring cages measured 0.9 to 1.2 m (3 to 4 ft) in height and 1.2 to 1.8 m (4 to 6 ft) in diameter and were designed to protect floating-leaved species (Figure 5). Ring cages were anchored with 1-in. PVC piping woven through the wire mesh and driven into sediments. Hoop cages measured 2 m (7 ft) in diameter and 1.8 m (6 ft) in height and were designed to protect submersed species. Hoop cages were stabilized by attaching 2.54-cm (1-in.) flexible tubing "hoops" to the top and bottom

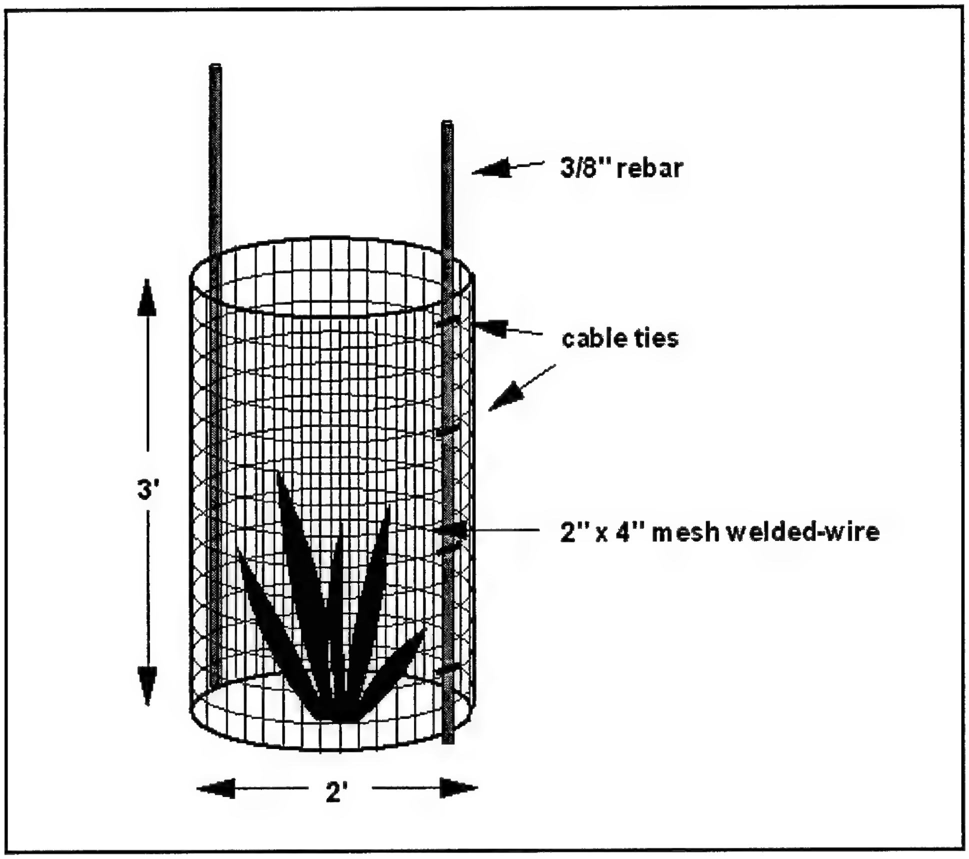

Figure 4. Tomato cages were designed to protect individual plants from large herbivores in Cooper Lake

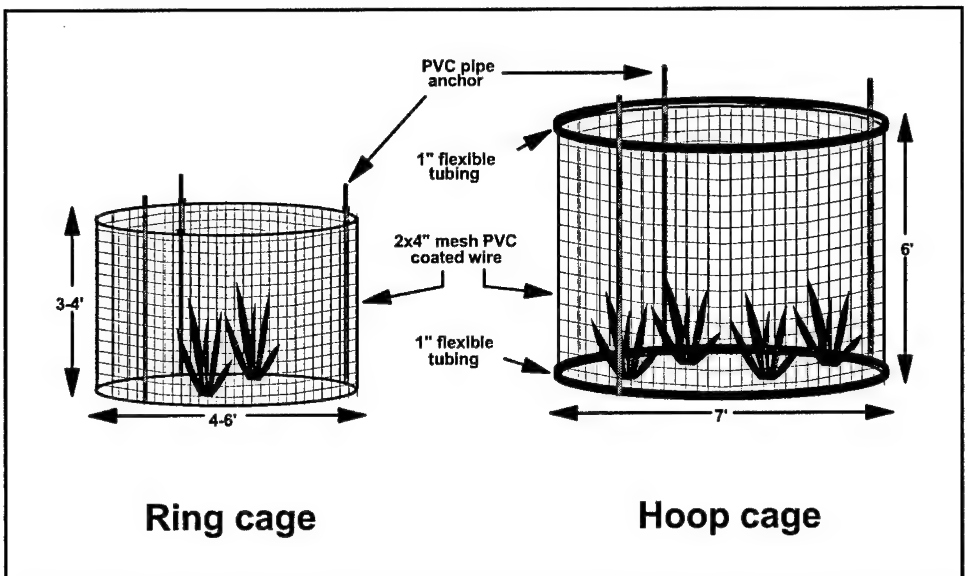

Figure 5. Ring and hoop cages designed to protect individual or small groups of plants in Cooper Lake

of the wire mesh cylinder. Hoop cages were anchored with PVC piping woven through the wire mesh or 15-cm (6-in.) tent stakes.

d. *Mesh size.* Materials used in the fence and cage construction were 2" × 4" mesh which excludes adult common carp and most grazing turtles, the two most widespread grazers in Texas reservoirs and both known to occur in Cooper Lake. Other grazers possibly found in the lake include crayfish and small turtles, either of which can cause significant damage to newly installed plants. Therefore, a test using a finer mesh was conducted to detect the need to protect plants from such smaller herbivores. Six tomato cages were wrapped with 2.5-cm (1-in.) diamond-mesh orange construction fencing to compare with survival of plants protected only by tomato cages. This test was conducted only at the no-fence site.

Planting Depth and Fluctuating Water Levels

Depth of planting is a concern when installing aquatic plant propagules. Because light penetration is critical to growth of submersed species, planting depth may vary dependent on water quality. Experience suggested that depth ranges for successful establishment of different growth forms of aquatic plants selected for Cooper Lake are as follows:

- Submersed species.. 30-120 cm (1-4 ft)
- Floating-leaved species .... 30-90 cm (1-3 ft)
- Emergent species... 0-30 cm (0-1 ft)

Plants should be placed in shallower water under high turbidity conditions during initial establishment, especially submersed species. Shallower planting depths allow greater light penetration (regardless of turbidity) and lead to better growth of new plants, thereby increasing the likelihood of establishment. However, because of fluctuating water levels in Cooper Lake, planting depths that are ideal for a particular species or growth form might become too deep for light penetration, starving the plant, or too shallow, killing the plant by desiccation. In 1998, this project addressed several concerns regarding planting depth in relation to changing water levels.

a. *Planting depth for submersed plants.* Various planting depths of a single submersed species were tested to ascertain the most successful planting depths in Cooper Lake. American pondweed was planted at seven depths: 30, 45, 60, 75, 90, 105, and 120 cm (1, 1.5, 2, 2.5, 3, 3.5, and 4 ft). Each depth was replicated six times, and each plant was protected with a tomato cage.

b. *Kiddie pools.* A test was devised to address the concern of plant loss resulting in changes in water level: plastic kiddie pools were filled to a depth of 15 cm (6 in.) with local sediments, moved to a depth of 90 cm (3 ft), and planted with submersed species. Each colony was protected from herbivory with a 150-cm (5-ft) diam welded-wire tomato cage. When the water level rose or fell by more than 90 cm (3 ft), kiddie pools

(and thereby plant colonies) were to be moved to depths that prevented desiccation.

c. *Floating cages.* A test was also conducted to address fluctuating water levels (as well as ascertain suitability for an additional plant species). Coontail (*Ceratophyllum demersum*) was placed in floating cages (Figure 6) constructed from 5-cm (2-in.) diamond mesh construction fencing. To overcome potential exposure during low-water events, floating cages were tethered to anchors in water 300 cm (10 ft) deep. This depth was not historically exposed during low-water conditions, but in the event that the water level dropped more than 240 cm (8 ft), the cages were to be moved to deeper water to avoid desiccation. Because coontail is not a rooted plant and receives nutrients from the water column, water fertility was a concern for establishment. This study was not aimed at producing sustainable founder colonies of coontail but rather colonies maintained by periodic restocking. After stocking a floating cage with plants, we anticipated wind and wave action would eventually wash all plant materials out from the cages. Once depleted, cages were to be restocked to sustain the propagule source.

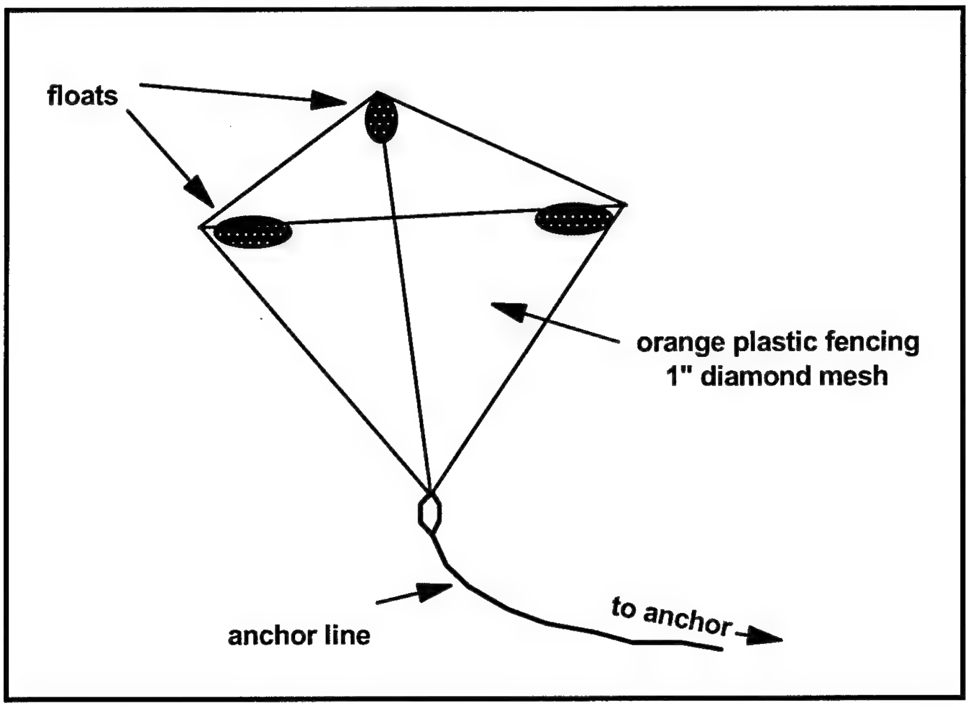

Figure 6. Floating cages were designed to contain coontail in deeper water

d. *Chasing water levels.* A method employed in 1999 to address water level fluctuations included construction of two 300-cm- (100-ft-) long shoreline pens (width dimensions variable, dependent upon contours) constructed from 2" × 4" mesh welded-wire and t-posts. Each shoreline pen was built from the conservation pool shoreline to a depth of 105 cm (3 ft) (Figure 7). These pens were constructed to protect most of the emergent, submersed, and floating-leaved species tested in the study.

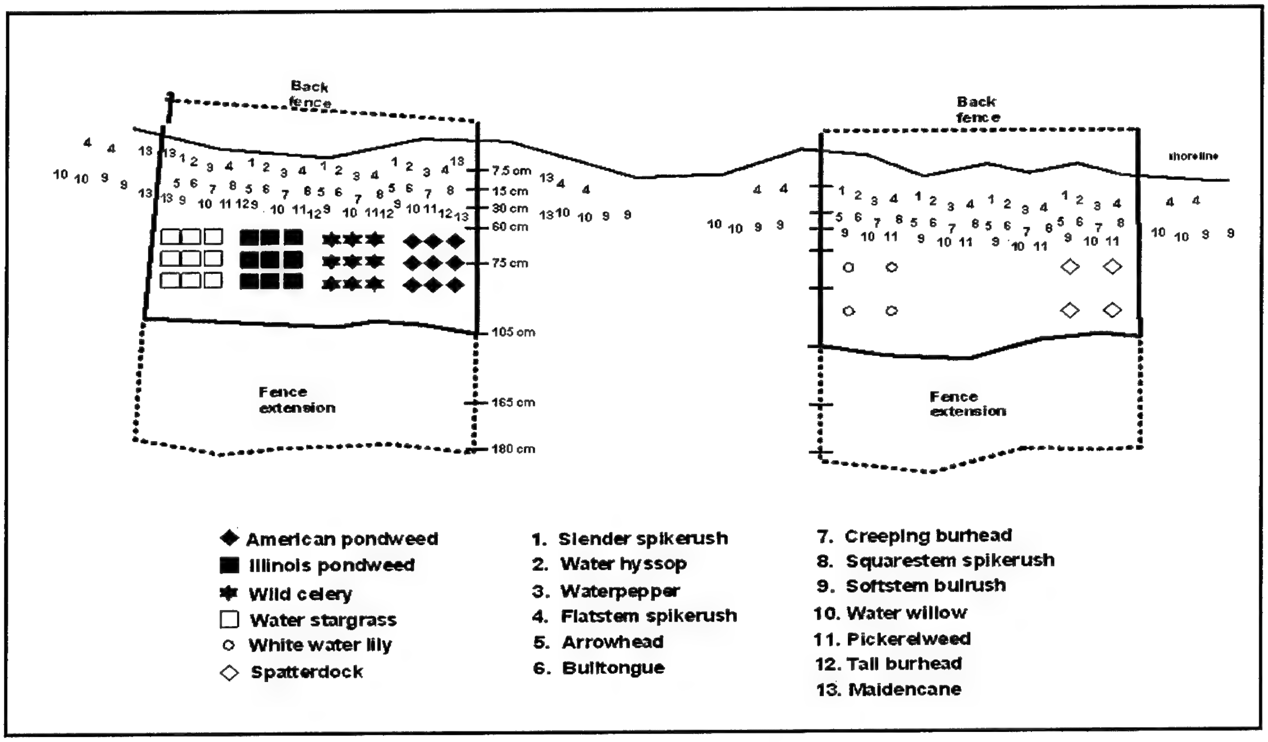

Figure 7. Planting scheme for aquatic plant establishment designed to overcome fluctuating water levels in Cooper Lake. This design was implemented near the end of the 1999 growing season (August 1999)

Four (4) submersed species and thirteen (13) emergent species were planted in one pen, and two floating-leaved species and thirteen (13) emergent species were then planted in the other. In contrast to the shoreline fence built in 1998, these pens included backs to prevent entry by terrestrial herbivores during low-water events. With each 60-cm (2-ft) incremental change in water level, an extension was added to the pens to a then-current depth of 105 cm (3.5 ft). This protected area was planted with the same species mix as the original planting, resulting in protected plants at various depths.

An additional method addressing fluctuating water levels was initiated in 2000. Hoop cages were installed and planted with submersed species at two-depth tiers, 6.0 and 120 cm (2 and 4 ft). When the water level fluctuated (decreased or increased) by 60 cm (2 ft), a third tier of hoop cages would be installed and planted at the then-current 60-cm (2-ft) or 120-cm (4-ft) depth (Figure 8). The goal of this study was to ascertain a method of sustaining propagule-producing founder colonies (of submersed species) throughout the growing season.

Timing of Planting

Each year's projects were initiated in May 1998, August 1999, and June 2000. Summer planting generally ensured that potted plants had broken

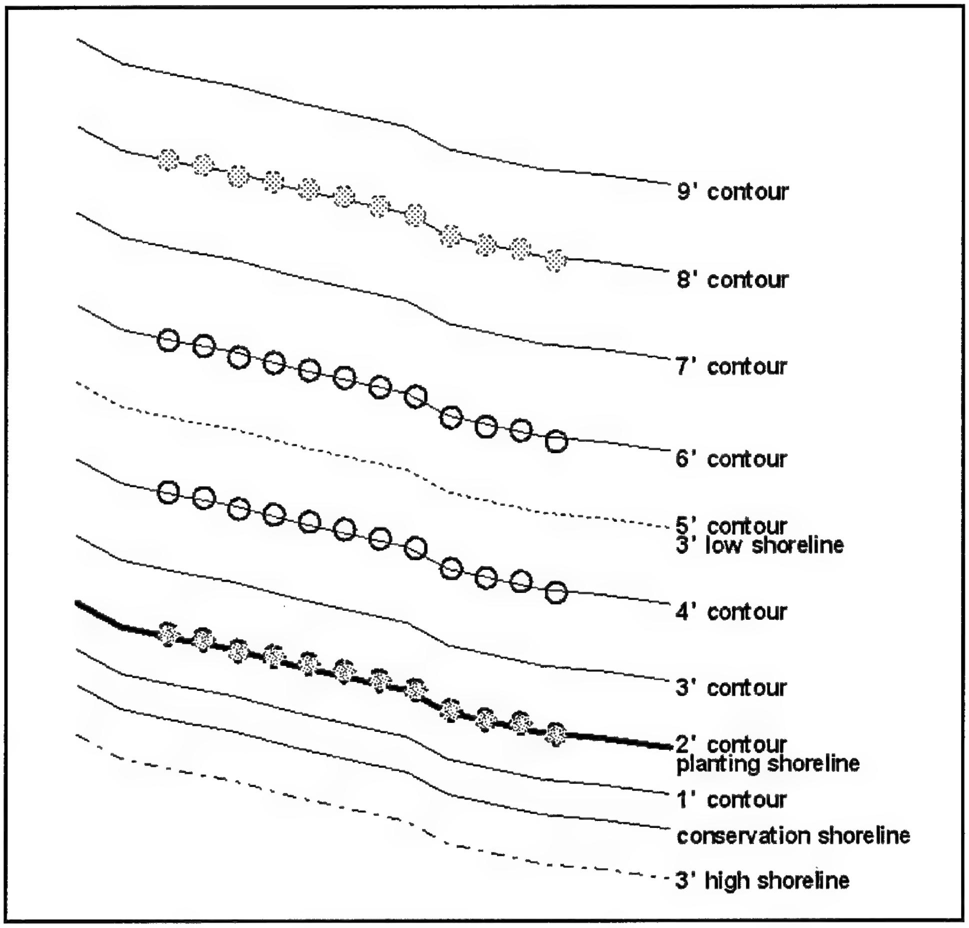

Figure 8. Multiple installations and plantings of hoop cages designed to address water level fluctuations in Cooper Lake

dormancy and/or had sufficient time to establish in pots prior to planting. Target depths for all species were relative to then-current lake elevation and not dependent upon conservation pool.

Surveys and Evaluations

In 1998, surveys were performed every month following planting. Observations on survival and measurements of area occupied by individual plants (or colonies) were made at these times. Rates of survival over a single growing season were used to evaluate which plant species were best suited for Cooper Lake in the short-term. However, species that had survived these short periods were not necessarily growing and may have been weaker than the originally planted propagules. To evaluate vigor of the plants, each specimen or colony was measured and compared with the initial area occupied by the planted propagule. Area of each plant or colony was calculated by averaging measurements of length and width (Figure 9). Multiple points were GPS-recorded (Trimble Pro-XRS) to calculate areas of colonies when widths were greater than 2 m. Sites were surveyed in the same manner in spring 1999 to assess recovery of plants

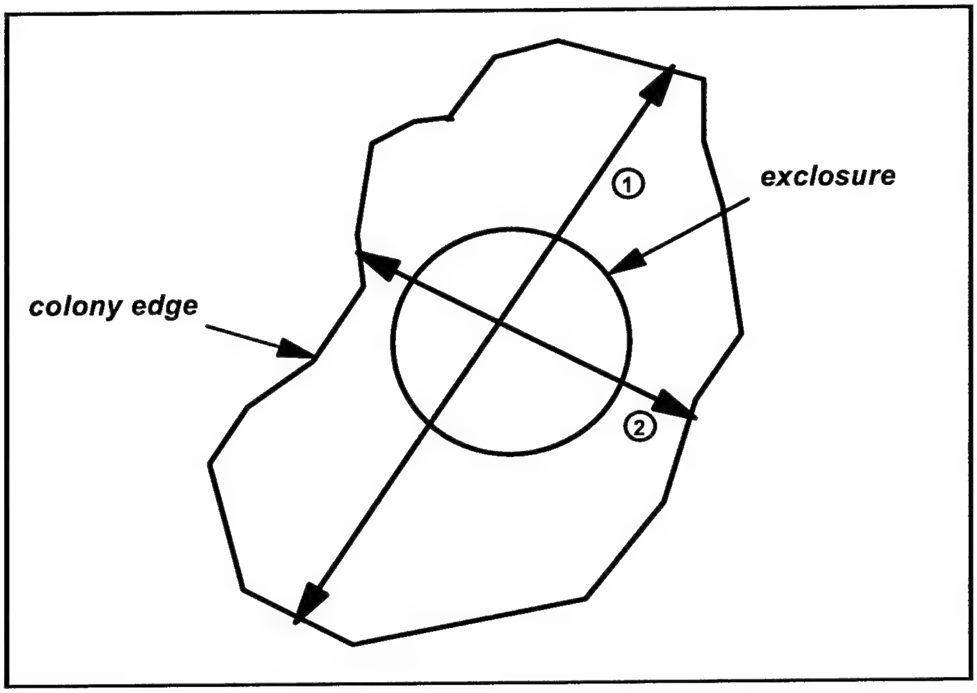

Figure 9. Plant and colony size estimates were made by measuring colony length, measuring colony width, averaging length and width, and recording as diameter

following winter dormancy. Following new plantings in 1999 and 2000, surveys were conducted every 4 to 6 weeks, with greater emphasis on GPS mapping spread from protective exclosures and development of new colonies in the general area of the study site. Spring assessments of all plantings were conducted each year to assess recovery of previous plantings. GPS-maps were generated using Pathfinder and Arc-View software.

Statistical Analyses

Survival was compared by plant species, by fence type, and by tomato cage protection in 1998. Interactions among these variables were also examined. Data were not normally distributed, so Chi^2 (CATMOD) tests were performed on survival data. Significance for all analyses was tested at the alpha 0.05 level. Chi^2 (CATMOD) tests were also performed on recovery of 1998 plantings in 1999. Statistical analyses on survival and spread in subsequent years (1999 and 2000) were not performed.

3 Results and Discussion

Results and Discussion: 1998

The site selected for the 1998 study (and subsequent studies) was represented by twin coves within a larger cove (Figure 10). Tests conducted during 1998 at these sites included species suitability, protection from herbivory (using large-, moderate-, and small-scale exclosures), evaluation of two mesh sizes for protective exclosures, evaluation of planting depths for submersed species, evaluation of submersed species found colony establishment in kiddie pools, and evaluation of coontail establishment from floating cages.

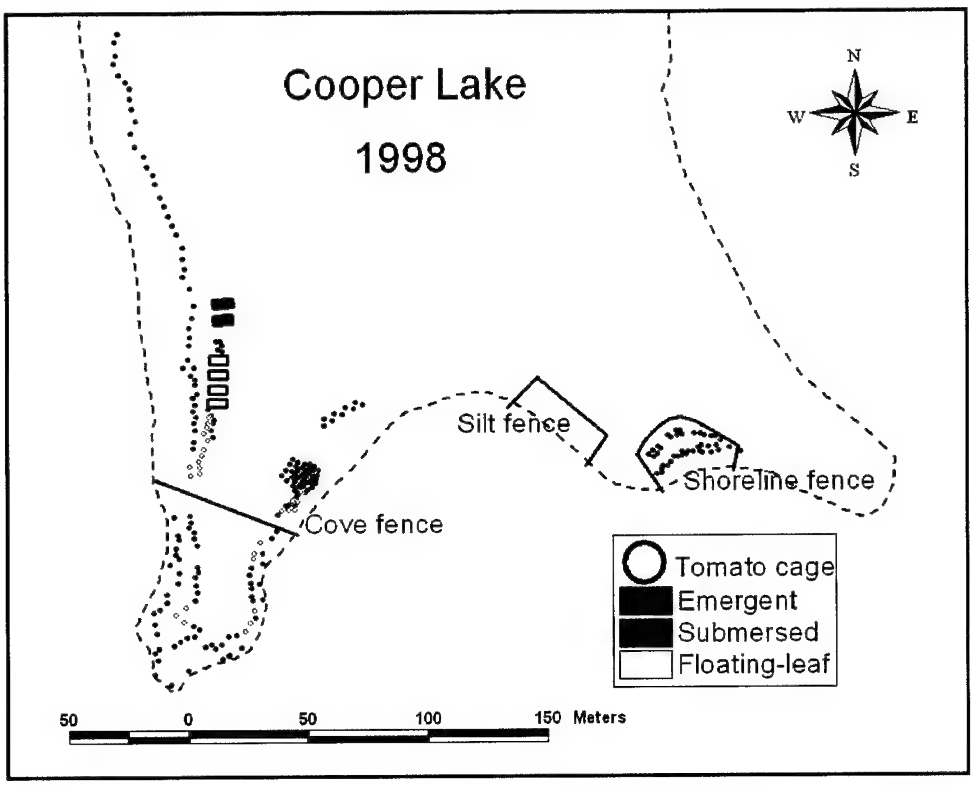

Figure 10. Protective exclosures and planting layout at test site selected in Cooper Lake in 1998

Survival was used as a short-term method for gauging suitability of aquatic plants tested. Additionally, survival data permitted evaluation of methods

designed to accommodate water depth and herbivory. In 1998, over 90 percent of the 25 species tested had survived after 2 months. Survival of emergent plants was contingent upon species ($p < 0.001$). Softstem bulrush, water willow, and flatstem spikerush exhibited higher than expected survival, while arrowhead and creeping burhead exhibited lower than expected survival. Survival of floating-leaved plants was also contingent upon species ($p < 0.001$). White water lily exhibited higher than expected survival, while watershield exhibited lower than expected survival. Survival of submersed plants was also contingent upon species ($p < 0.001$). Illinois pondweed exhibited higher than expected survival, while sago pondweed exhibited lower than expected survival. Although robustness of propagules, life history, selective grazing, and water level changes may have played roles in these differences, it was clear that some species were more suitable for establishment in Cooper Lake than others. Because of no survival, sago pondweed and watershield were eliminated as restoration candidates. Following the 2-month assessment, apparent survival was greatly reduced because of the onset of a 2-year drought in east Texas: by October 1998, the water level had fallen to more than 60 cm (2 ft) below conservation pool, leaving many plants above the waterline until winter, when rains filled the lake to normal pool.

Large-scale protection

Survival of emergent plants was not contingent upon the presence of fencing ($p = 0.25$) after 2 months. Neither fence type (shoreline and cove) was designed to prevent terrestrial herbivores from entering the planted sites, with a decrease in water level increasing the likelihood of terrestrial grazing. Survival of floating-leaved plants was not contingent upon the presence of the cove fence ($p = 0.18$). Floating-leaved plants were not tested in the shoreline fence. Survival of submersed species was not contingent upon the presence of fencing ($p = 0.26$). Although not statistically significant because of high variability, submersed plants without any protection survived at much lower rates than those behind fences without the additional protection of tomato cages, implying that the fences were reducing damage resulting from herbivory to some degree. Most plants appeared to survive low-water conditions in the fall 1998.

Moderate-scale protection

Survival of submersed plants in pens averaged 100 percent after 2 months. Growth was assessed by percent coverage estimate within a pen (5-percent coverage was the initial estimate in each pen). American pondweed averaged 85-percent visible coverage, water stargrass averaged 60-percent coverage, and wild celery averaged 20-percent coverage. In most cases, pens exhibited full coverage by aquatic plants. In addition to planted species, southern naiad and muskgrass were present in areas not filled by planted species. The source of these plants was likely from seeds and spores introduced with the transplants. American pondweed and water stargrass continued to persist in pens during low-water conditions (each pen was in approximately 30 cm (1 ft) of water in October). Wild celery was present, but appeared to have declined (covering about 5 percent of each pen in which it was planted) by October.

Small-scale protection

After 2 months, survival of emergent, floating-leaved, and submersed species was contingent upon protection by tomato cages ($p < 0.001$). Higher than expected survival was seen in the presence of tomato cages, while higher than expected mortality occurred when no cage was present. Tomato cages were apparently effective against aquatic and terrestrial grazers. Although several species did not appear to require protection in the short-term, exclusion of grazers from newly transplanted propagules was concluded to be necessary for establishment of aquatic plants in Cooper Lake. Those exceptions included softstem bulrush, flatstem spikerush, and water willow.

Mesh size

The test in which two mesh sizes, 2" × 4" upright rectangular and 2.5-cm (1-in.) diamond, were used to protect American pondweed from herbivory, indicated that the larger mesh was adequate for protection of plants in Cooper Lake. After 2 months, 100-percent survival was observed in the larger mesh cages and 88 percent was observed in smaller mesh cages. No survival was recorded for plants installed without protection. Although mesh size was not a factor in survival of American pondweed, survival of other submersed species might still be affected by smaller herbivores. Testing of other species was not undertaken.

Depth planting

American pondweed was planted (and protected with tomato cages) at multiple depths to ascertain the optimal planting depth for submersed species, when 1-month, 2-month, and final assessments were made. Higher survival at shallower depths was noted 1 month after planting, although after 2 months, Chi^2 analysis indicated that survival was not (marginally) contingent upon planting depth ($p = 0.054$). Several factors may have greatly influenced these results, the principal being changes in water level during the 3-month period of data collection. Highest survival at the 1-month survey was seen at 30, 45, and 60 cm (1, 1.5, and 2 ft), with a decline in survival associated with greater depths. In all likelihood, plants at greater depths remained alive but had not yet grown to the surface (or were suffering damage because of abrasion against cage sides), making survival difficult to assess visually. Highest survival at the 2-month survey occurred at 60-cm (2-ft) planting depth, which at that time was actually less than 30 cm (1 ft) deep. Low survival at 30 and 45 cm (1 and 1.5 ft) was attributable to reservoir water loss and subsequent exposure at that time. By fall 1998, continued water level declines led to apparent mortality at many shallower depths. Plants at 75 cm (2.5 ft) and greater depths apparently exhibited higher survival rates, most likely because these remained under water.

Planting depths of submersed species appears to be important initially: plants establish and grow more quickly when planted in shallow water. However, the confounding factors of water level changes and probable damage to the plants by tomato cages made identification of optimal planting depths impractical based

upon this test. Shallow plantings initially exhibited high survival rates and grew vigorously compared with deeper plantings, but the falling water level exposed them to desiccation and possible mortality. Deeper plantings did not establish as readily, but growth appeared to increase as the water level dropped.

Kiddie pools

Submersed plant colonies were successfully established in kiddie pools (planted at 60-cm (2-ft) depth) 2 months after planting. Planted species were present and had spread to fill each pool into which they were planted. Additionally, southern naiad and muskgrass were observed in the pools, likely introduced by seed and spore when potted plants were installed. By fall 1998, the water level had dropped by over 60 cm (2 ft), leaving the pools exposed. At that time, only American pondweed and water stargrass appeared to have survived exposure to desiccation (wild celery was not observed). Attempts to move pools to deeper water were unsuccessful. Although keeping founder colonies alive under fluctuating water level conditions by planting in kiddie pools was successful in the short-term, the difficulty in relocating them led to the conclusion that it is not a practical method for long-term maintenance of founder colonies in Cooper Lake.

Floating cages

All 18 floating cages retained coontail 1 month after stocking, and 16 of these retained plants after 2 months. However, the volume of plant material remaining had declined appreciably, from an average of 12 L per cage to an estimated average of 5 L per cage. By the fall 1998 assessment, few cages held plants, and the average estimated volume was less than 0.2 L. Despite the lowered water level, floating cages remained in sufficiently deep water (90 cm (3 ft) or greater), and desiccation was not a factor in loss of plants. Some cages were lost, presumably a result of wave action damage. No coontail was found growing in the immediate vicinity of floating cages. Plans to restock the floating cages were abandoned after a failure to locate coontail colonies that were not infested with hydrilla.

Silt fence

The silt fence exhibited about 80-percent coverage at the 2-month survey and included southern naiad, muskgrass, American pondweed, and bulltongue. Although the fenced area was exposed to desiccation by the time of the fall 1998 assessment, at some earlier point it had been heavily damaged by waves (and/or wind). Because of this susceptibility to damage, the use of this fence type was deemed inappropriate for establishment of vegetation in Cooper Lake.

Results and Discussion: 1999

A survey was conducted in May 1999 to assess recovery of plants installed in 1998. Although the water level had returned to conservation pool during the winter, operational maintenance of the dam required a 120-cm (4-ft) draw down in spring 1999. This lowered water level was maintained for about 1 year, until dam repairs were completed. Two shoreline pens were constructed relative to conservation shoreline in August 1999. Because the deep end of each pen extended only to the then-current shoreline, extensions were built to increase the protected depth to about 120 cm (4 ft), with each extension measuring approximately 8 m (25 ft) in width. Four (4) submersed species and thirteen (13) emergent species were planted in one pen extension, and two floating-leaved species and thirteen (13) emergent species were planted in the other. Because 1998 data indicated that several species might not require protection for establishment in Cooper Lake, these were further tested in 1999. Softstem bulrush, flatstem spikerush, and water willow were planted in and out of protective exclosures (pen extensions) in this study. Additionally, a species not tested in 1998, maidencane, was planted with and without protection. Two moderate-scale (3.6- × 3.6-m (12- × 12-ft)) pens were constructed at a depth of 75 cm (2.5 ft) and each planted with four potted American lotus plants; four American lotus plants were also planted without protection.

Recovery of 1998 plantings

Evaluation of plant recovery following winter was intended to gauge longer-term suitability of aquatic plants tested in Cooper Lake (Figure 11). Because recovery of all species was influenced by low-water conditions maintained during dam repair, these data may not predict reasonable expectations of recovery under normal conditions occurring in the lake. However, these same extreme conditions provided an opportunity to evaluate which species might be best suited for long-term survival in the face of potential flood control operations. Those better adapted to surviving such periods of desiccation would likely be preferred candidates for full-scale establishment efforts in Cooper Lake.

As stated in methods, the three different growth forms were planted at different depths in 1998:

- Submersed species... 60 cm (2 ft)
- Floating-leaved species .... 45 cm (1.5 ft)
- Emergent species... 0-30 cm (0-1 ft)

The exception to this planting depth regime was the depth study, which included planting American pondweed at incremental depths up to 120 cm (4 ft) deep.

In May 1999, observed recovery of plants installed in 1998 was higher than expected ($p < 0.0001$) and was contingent upon species ($p < 0.0001$). Despite most plants being out of water, many species continued to survive, in part because soils in which they were planted remained moist. In most cases,

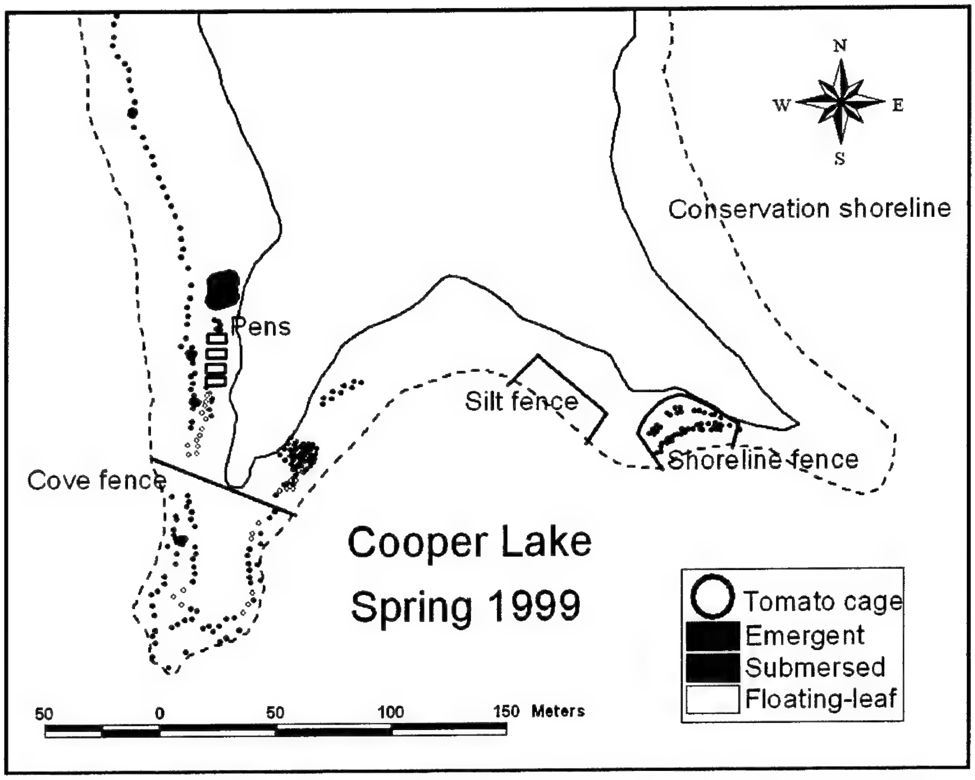

Figure 11. Recovery of 1998 plantings in Cooper Lake in May 1999. The water level had been drawn down by 1.2 m (4 ft) in order to make repairs on the dam, and most plants were out of the water

terrestrial species (mostly grasses and sedges) had begun to invade planted areas. For emergent species, softstem bulrush and water willow exhibited higher than expected recovery, while arrowhead and tall burhead exhibited lower than expected recovery. For floating-leaved species, white water lily exhibited higher than expected recovery, while watershield exhibited lower than expected recovery. Spatterdock recovered at expected rates. For submersed species, water stargrass exhibited higher than expected recovery, while sago pondweed exhibited lower than expected recovery. Water stargrass develops into a terrestrial form when exposed for short periods and may be more tolerant of desiccation than other submersed species tested. Other species recovered at expected rates. Tolerances to desiccation and terrestrial herbivory are believed to have contributed to differences in survival among species.

Recovery of emergent and floating-leaved species was not contingent upon the presence of fencing ($p = 0.105$). Shoreline and cove fences apparently did not protect emergent species from herbivores, which potentially had shifted from aquatic to terrestrial grazers following a drop in water level. Recovery of submersed species was contingent upon the presence of fencing ($p = 0.015$). Recovery was higher than expected in fenced coves, while lower than expected in unfenced sites. Principal herbivores on submersed species were apparently aquatic (carp and turtles), and both cove fences and shoreline fences were able to protect the plants in those few areas that had retained sufficient water to support submersed plants.

Recovery was contingent upon protection by small-scale exclosures (tomato cages) for emergent ($p < 0.0001$), floating-leaved ($p < 0.0001$), and submersed ($p = 0.006$) species. Higher than expected recovery was seen in the presence of tomato cages, while higher than expected mortality occurred when no cage was present.

Table 2
Mean Percent Recovery of Three Aquatic Plant Growth Forms after 12 Months (June 1998 through May 1999) in Cooper Lake

Growth Form	Overall % Recovery	Tomato Cage % Recovery	"No Tomato" Cage % Recovery
Emergent	62	55	40
Floating-leaved	35	56	15
Submersed	7	17	10
Mean	**35**	**43**	**22**

Numbers of plants recovering were low compared with survival of plants at the 2-month survey (Table 2). The lowest rates of recovery were seen in the submersed plant group (7-percent average), attributable to plant mortality that occurred when the declining water level left plants exposed to desiccation. Although planted at shallower depths and exposed to desiccation sooner than submersed plants, floating-leaved plants were more tolerant of desiccation and recovered at higher rates. Emergent species, the most desiccation-tolerant of the three growth forms, recovered at the highest rates. Herbivory continued to play a role in recovery rates and was especially evident in the case of floating-leaved species. However, failure of some unprotected plants to recover may be attributable to losses before low-water conditions.

Recovery of plant colonies in pens averaged 67 percent in spring 1999, despite being exposed to desiccation: American pondweed and water stargrass exhibited 100-percent recovery, but wild celery did not recover in either pen in which it was planted. Soils inside pens remained adequately moist to support the two surviving species, while the loss of wild celery between the fall 1998 survey and spring 1999 survey was attributed to desiccation following drawdown. In comparison, average recovery for all three species planted at the same depths and protected by tomato cages was only 17 percent. Two factors may have contributed to the higher recovery of plants protected by pens:

a. Pens were less likely to cause damage to the plants than tomato cages. The small size of tomato cages made all elongating shoots susceptible to abrasion against the cage material during windy (high wave action) conditions. This sort of damage might be especially critical to colony survival in terms of its ability to produce over wintering (or desiccation resistant) structures during the 1998 growing season.

b. Colonies in pens covered a considerably larger area (11.5 m^2 versus 0.75 m^2) and their greater biomass may have served to produce greater numbers of over wintering propagules (tubers, roots and stem bases) than those in tomato cages. This suggested that colony size might play a role in the ability of submersed species to successfully recover from winter and/or dry-condition dormancy.

In all, three submersed species (wild celery, Illinois pondweed, and sago pondweed), one floating-leaved species (watershield), and one emergent species

(arrowhead) had not recovered the year following planting. Failure of these and some individuals of other species to recover was apparently caused by to one or a combination of two major factors:

a. *Herbivory*--protected plants recovered at higher rates than unprotected plants. The type (or level) of protection was important: tomato cages offered a high level of protection, while large-scale protective devices were more easily breached by herbivores and recovery was lower.

b. *Desiccation*--exposure during low-water events increased mortality of plants. This was true regardless growth form: emergent, floating-leaved, and submersed plants suffered during the low-water period, although emergent species were evidently much more tolerant than the other two growth forms.

Despite the harsh conditions to which plants had been subjected and continued to endure, most species had recovered, and in some cases, spread from protected areas was noted. Softstem bulrush, squarestem spikerush, flatstem spikerush, slender spikerush, water hyssop, and water willow all had grown beyond tomato cages, forming colonies as large as 1 m in diameter.

Survival of 1999 plantings

Six (6) weeks following construction and installation, the water level had dropped by about 30 cm (1 ft). However, all species and 97 percent of individual plants transplanted had survived. Species not exhibiting 100-percent survival included American lotus (25-percent survival protected, 0-percent survival unprotected), maidencane (25-percent survival protected, 0-percent survival unprotected), softstem bulrush (50-percent survival unprotected), flatstem spikerush (89-percent survival unprotected), water willow (87.5-percent protected), American pondweed (89-percent survival), Illinois pondweed (89-ercent survival), squarestem spikerush (87.5-percent survival), and tall burhead (83.5-percent survival). Reasons for these losses were attributed to herbivory (unprotected plant loss, most notably unprotected softstem bulrush and American lotus) and weak propagules (maidencane).

American lotus had begun to spread beyond protective pens, but growth outside each pen was heavily damaged by grazing, evidently by turtles. Stolons remaining within the pens failed to sprout new tips, resulting in plants in decline. Although inadequate pen size may have been in part responsible for poor establishment of lotus, it was more likely the result of low survival and inadequate numbers of propagules. Greater survival might have increased the chances of stolons growing inside the pens as well as outside. Additionally, American lotus begins senescence to dormancy relatively early in the growing season and is generally near dormancy by the end of September in east Texas. The late planting may have contributed to the apparent failure of this species to establish.

Growth of 1999 plantings

Plants in the shoreline pens had expanded from an actual planted area of 1.7 m^2 to cover an area of 31.8 m^2 after 6 weeks (Figure 12). Most species had grown between the planting and assessment dates, implying conditions were conducive to successful establishment at least during a part of this time. Exceptions were maidencane (protected and unprotected), flatstem spikerush (unprotected), water willow (unprotected), and slender spikerush, all of which had apparently declined in area following planting. Growth loss on unprotected species (but not protected species) implied that grazing might have been inhibiting establishment. The lower water level at this time did not appear to be a factor in growth failure of any species.

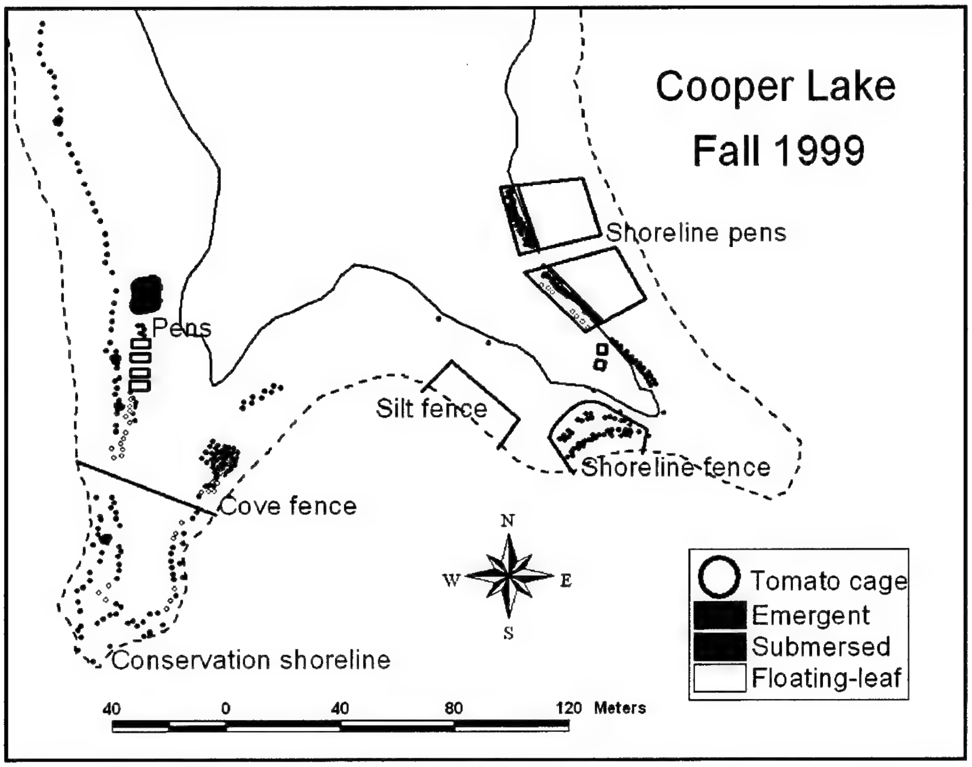

Figure 12. Additional exclosures (shoreline pens with extensions and pens for American lotus) were installed at the study site. Plants had begun to spread within these exclosures after 6 weeks, and some emergent species were spreading beyond tomato cages, despite low-water conditions

Growth of all species was limited to a short period (6 weeks instead of a full growing season). Therefore, these data should not be used for evaluation of long-term suitability of plants for Cooper Lake. On average, expansion within protected areas was greatest in floating-leaved species. Submersed species also spread quickly, indicating potential fast rates of colonization. Emergent plant spread was variable and apparently most dependent upon characteristics of individual species.

Herbivory on 1999 plantings

All protected softstem bulrush plants survived the 6-week period between planting and evaluation. Additionally, average growth from the original plants (as determined by area) was by a factor of 3.5. Unprotected softstem bulrush exhibited 67-percent survival and average growth was by a factor of 3. With protection, survival was higher and growth was greater than without protection. It appeared that nutria or beaver were feeding on roots of this species. These data suggest that softstem bulrush should be protected from herbivores in Cooper Lake.

All protected flatstem spikerush plants survived the 6-week period. Additionally, average growth was by a factor of 11. Unprotected survival was 93 percent, and unprotected average expansion was by a factor of 9. Although slight differences between unprotected and protected plants occurred, evidence of grazing was not observed. Flatstem spikerush may not require protection from herbivores in Cooper Lake.

Protected water willow plants survived at a rate of 98 percent over the 6-week period. Additionally, average growth was by a factor of 5. Unprotected survival was slightly lower at 93 percent and unprotected average expansion was by a factor of 4. Evidence of browsing by deer was noted on most individual plants. Another species of water willow, lance-leaf water willow, in many cases growing adjacent to the test species, did not show signs of herbivory. Herbivore damage was not excessive, and water willow may not require protection from herbivores in Cooper Lake.

Maidencane plant survival was relatively low, with only 54 percent of those protected surviving the 6-week period. Additionally, average expansion was by a factor of 4. Unprotected survival was 46 percent, and unprotected average expansion was by a factor of 2. Signs of herbivory were not noted, and because maidencane is found in other areas of the lake, the test was most likely affected by variation in propagules. The species was a last-minute addition to the study, and stems only had 2 weeks to set roots in pots.

Water level

The water level in Cooper Lake fell slowly following the 1999 plantings, dropping about 45 cm (1.5 ft) below the 120-cm (4-ft) drawdown by October. Because the water level did not rise or fall by 60 cm (2 ft), modifications to shoreline pens were not required.

Results and Discussion: 2000

The water level returned to conservation pool by early May 2000 and was at conservation pool in June 2000, when an assessment was conducted on plants installed during 1998 and 1999 (Figure 13). All planting sites installed in 1998 were underwater. At the time of this assessment, additional plants were installed

in the shallower portions of the shoreline pens: this planting followed the original "chasing water levels" plan, at which multiple plantings would be used to maintain actively growing founder colonies in well-protected areas. Water had reached conservation pool; the shoreline pens were fully inundated and thereby suitable for planting. At the same time, the extension of each pen (planted in 1999) was topped over by water and was potentially exposed to herbivory by carp and turtles that were now able to swim over the top of the extension fencing. Hoop cages ((1.8-m tall × 2-m diam (6-ft tall × 7-ft diam)) were constructed and planted with submersed species at two depth tiers, 0.6-m (2-ft) and 1.2-m (4-ft) deep in June 2000, parallel to the shoreline adjacent to the shoreline pens. As part of continuing "chasing water level" experiments, additional sets were to be installed and planted in response to specific incremental changes in water level.

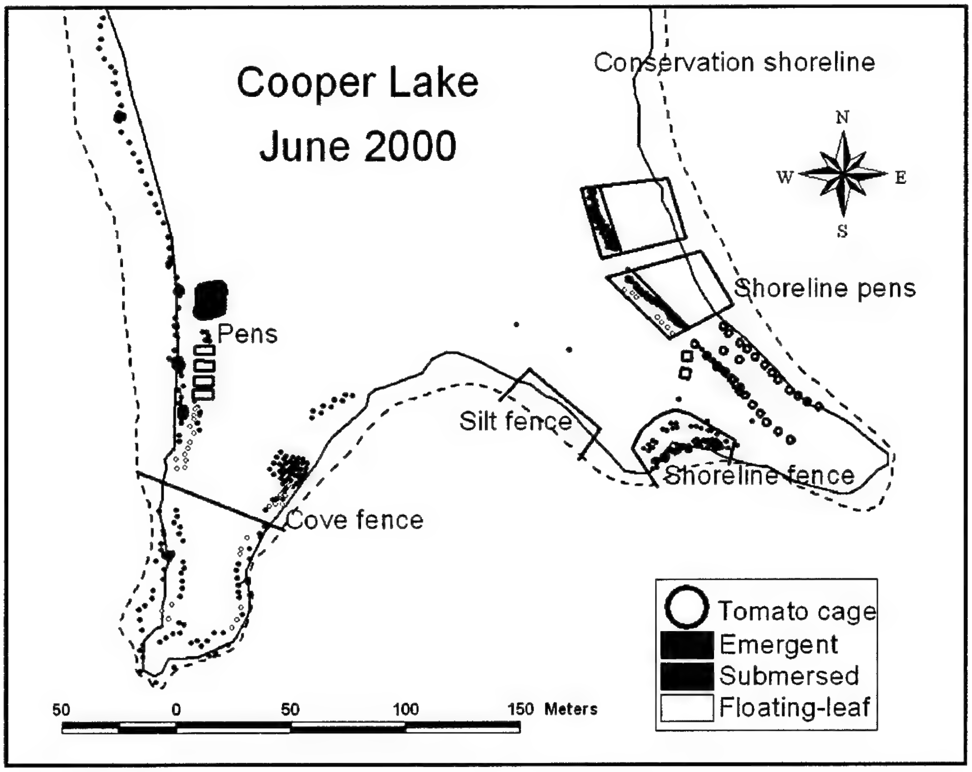

Figure 13. June 2000 assessment of 1998, 1999, and 2000 plantings in Cooper Lake. The water level was at conservation pool and hoop cages had been installed in order to "chase water levels"

Recovery of 1998 plantings

Several emergent species planted in 1998 that had persisted during low water in 1999 exhibited strong recovery and spread by 2000 (Figures 13 and 14). Soft-stem bulrush, water willow, squarestem spikerush, flatstem spikerush, slender spikerush, water hyssop, and creeping burhead all recovered and had spread to well outside protected areas. Despite weak presence throughout 1999, no floating-leaved species had recovered. Submersed species exhibited some recovery, with small colonies of American pondweed and water stargrass evident in both protected and unprotected areas at the time of assessment. However, at

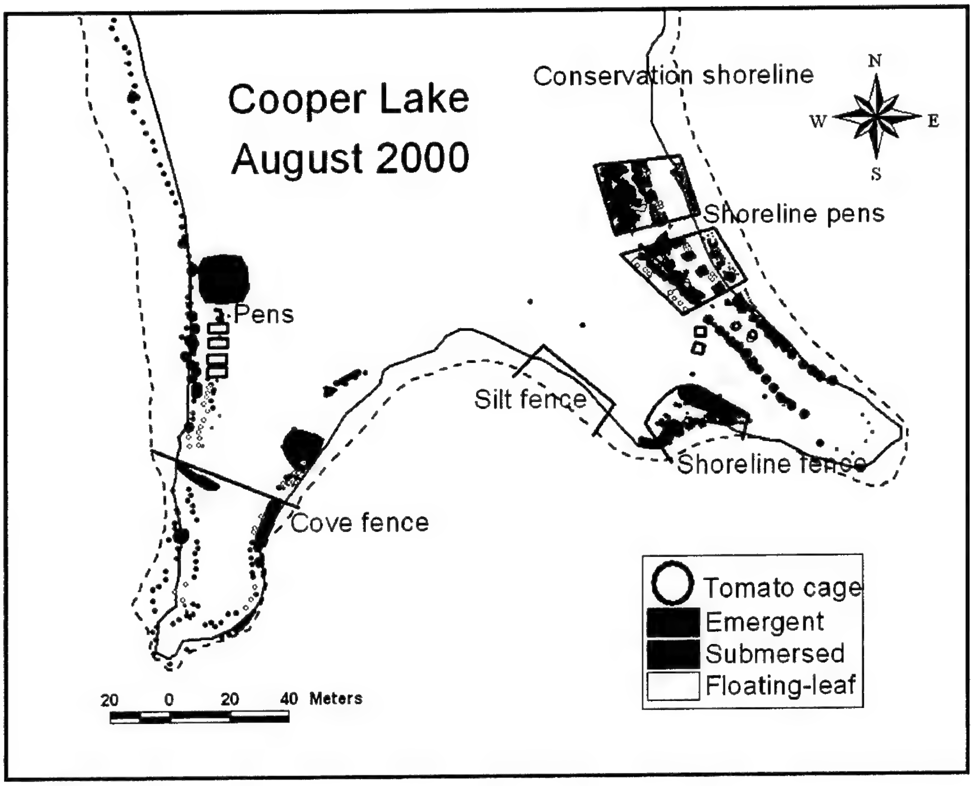

Figure 14. August 2000 assessment of 1998, 1999, and 2000 plantings in Cooper Lake

this time it was no longer possible to tell if these plants represented recovery from old colonies or the development of new colonies from propagules produced by 1999 plantings. Most fences and pens were showing signs of degradation, and PVC-coated, 3.8-cm (1.5-in.) hexagonal mesh poultry netting was installed around each to ensure exclosure integrity. Degraded tomato cages were removed from the study sites.

Recovery of 1999 plantings

Wild celery, American and Illinois pondweeds, water stargrass, white water lily, and spatterdock exhibited strong recovery: despite being topped over by water, both shoreline pen extensions were nearly filled with submersed or floating-leaved plants, and some spread outside the fences (American pondweed, water stargrass, and white water lily) was noted (Figures 13 and 14). Evidence of grazing (by carp or turtles) on these species was observed, and fragments of most species were abundant within the exclosures. Although water levels were near conservation pool (1.2 m (4 ft) greater than at the 1999 planting depth), several emergent species, including softstem bulrush, squarestem spikerush, pickerelweed, water willow, and tall burhead, persisted even at these depths (1.5 m (5 ft) deep). By the end of the growing season (October 2000), most of the plant biomass in the deepwater extensions had disappeared, apparently because of grazing (submersed and floating-leaved species) and excessive depths (emergent species).

However, sparse patches of all four submersed and both floating-leaved species persisted in the extensions.

Survival of 2000 plantings

Survival of all emergent species planted in shoreline pens and hoop cages was noted in October 2000, even though water levels had fallen by about 60 cm (2 ft) during that time (Figure 15). The 60-cm (2-ft) drop in water level should have triggered planting of an additional tier of hoop cages, but because the growing season was near its end, this planting was not undertaken. In addition, this same drop in water level should have triggered new construction of shoreline pen extensions and replanting, but because the extensions built in 1999 during low-water conditions remained flooded and populated with plants, this was not necessary. White water lily and spatterdock had spread within shoreline pens. Wild celery, American pondweed, Illinois pondweed, and water stargrass had grown to fill both shoreline pens. These same four species exhibited 100-percent survival in hoop cages at both planting depths (60 and 120 cm (2 and 4 ft)). Two ring cages planted with American lotus and a combination of submersed species continued to support the submersed species, but the lotus apparently did not survive.

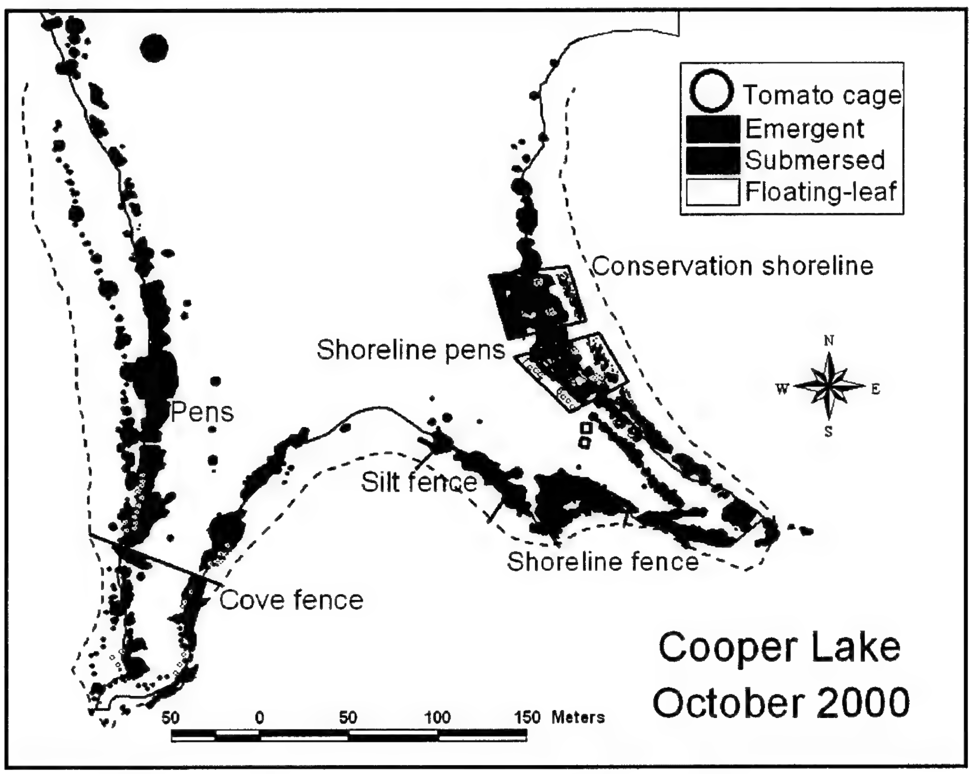

Figure 15. October 2000 assessment of 1998, 1999, and 2000 plantings in Cooper Lake

Spread

By October 2000, spread (growth outside of protected areas) was observed for all surviving 1998-planted emergent species except for softstem bulrush, which had been damaged by nutria or beaver (Figure 15). In addition, submersed species planted in hoop cages had spread to form single colonies surrounding those cages. Perhaps most significantly, colonies of American pondweed, Illinois pondweed, and water stargrass were observed along unprotected shorelines of most of the coves representing the study sites. Several patches of wild celery were found intermingled with these colonies. At this point, spread to unvegetated sites appeared to support the premise of aquatic habitat restoration in large reservoirs, and specifically in Cooper Lake. Evidently, more propagules were being produced than herbivores were able to consume, resulting in the formation of new colonies.

4 Conclusions

This project has identified a number of emergent, floating-leaved, and submersed aquatic plant species as suitable for establishment in Cooper Lake (Table 3). These species exhibited tolerance of low-water conditions and/or herbivory that occurred over the course of the tests. Emergent species exhibited tolerance to low-water conditions, surviving and growing well beyond protective cages between during 1999, when the lake was drawn down by 1.2 m (4 ft). These same species persisted and continued to spread when the lake returned to conservation pool. Floating-leaved species (white water lily and spatterdock) were not tolerant of long-term desiccation, but did grow well within protected areas. Several submersed species exhibited some tolerance to long-term drought (American pondweed and water stargrass), although others were not able to survive (wild celery and Illinois pondweed). All submersed species exhibited not only spread from protected areas, but establishment of new colonies from fragments or seeds.

Table 3
Aquatic Plants Deemed Suitable for Establishment of Founder Colonies in Cooper Lake

Common Name	Species Name	Growth Form	Drought Tolerance[1]	Herbivore Tolerance[1]
American pondweed	*Potamogeton nodosus*	Submersed	Fair	Good
Water stargrass	*Heteranthera dubia*	Submersed	Fair	Good
Illinois pondweed	*Potamogeton illinoensis*	Submersed	Poor	Good
Wild celery	*Vallisneria americana*	Submersed	Poor	Fair
White water lily	*Nymphaea odorata*	Floating-leaved	Fair	Fair
Spatterdock	*Nuphar luteum*	Floating-leaved	Fair	Fair
Squarestem spikerush	*Eleocharis quadrangulata*	Emergent	Good	Good
Flatstem spikerush	*Eleocharis macrostachya*	Emergent	Good	Good
Slender spikerush	*Eleocharis acicularis*	Emergent	Good	Good
Water hyssop	*Bacopa monnieri*	Emergent	Good	Good
Creeping burhead	*Echinodorus berteroi*	Emergent	Good	Good
Softstem bulrush	*Scirpus validus*	Emergent	Good	Poor
Water willow	*Justicia americana*	Emergent	Good	Good

[1] Tolerance ranks: Good---observed recovery and spread beyond protected areas; fair---observed recovery with no spread; poor---no observed recovery.

Protection from herbivores in Cooper Lake was essential for establishment of all aquatic plants tested. No plants installed without protection persisted more than one growing season. However, once plants had become established inside of protected areas, many species were able to grow outside the exclosures. Although not tested in these studies, the ability of protected founder colonies to spread beyond exclosures was likely a function of biomass production (new growth) exceeding grazing rates. The relatively small biomass of newly installed potted plants was evidently not enough to overcome these same herbivory rates.

Most protective exclosures performed well for at least one growing season. Those constructed from galvanized wire began to degrade during the second growing season, and replacement with PVC-coated galvanized wire was necessary. Because the length of time required for establishment and spread of founder colonies is not known, more durable materials might be most economically viable for protecting plants in Cooper and other Texas lakes.

Several exclosure types were deemed unsuitable for establishment of some kinds of aquatic plants. Tomato cages proved to be too small in diameter, apparently damaging leaves and stems of submersed and floating-leaved species suspended in the water column. Larger diameter hoop cages remedied this problem. Tomato cages were suitable for establishment of more rigid-stemmed emergent species. The silt fence was considered unsuitable as an exclosure for any plant type because of its susceptibility to wave damage.

The fact that water-level fluctuations might influence establishment and potential spread of founder colonies in Cooper Lake became apparent soon after the project was initiated. In addition to normal flood control operations (generally, catching water during the rainy season and releasing it slowly to circumvent downstream flooding) and cyclic drought lowering the water level by as much as 0.91 m (3 ft) in a single growing season, the water level was lowered by 1.2 m (4 ft) after initial plantings in 1998 in order to conduct dam maintenance procedures. The water level remained low for approximately 1 year. At one point, the water level fell more than 1.8 m (6 ft) below conservation pool (historic low). Experiments designed to ensure that founder colonies were present and producing propagules during the growing season addressed these unstable water conditions. "Chasing water levels" by construction of deepwater extensions from shoreline pens and by installation of hoop cages and multiple depths both successfully overcame this problem. Established in 1999, submersed plant founder colonies persisted in deepwater extensions throughout 2000. The water level did not fall enough to merit additional plantings, but hoop cages planted at a depth of 1.2 m (4 ft), also supported submersed species during the entire year. Although the source of fragments and seeds could have come from both or either shoreline pen extensions or hoop cages, in either case significant establishment of new colonies (predominantly American pondweed and water stargrass) had occurred throughout the study site by the end of the 2000 growing season (Figure 16). This phenomenon represented an unexpected bonus during this part of the project: significant (new colonies covered a greater area than protected colonies and their immediate spread) development of new colonies supports the premise of lake-wide restoration through founder colony establishment and subsequent spread. Because of the impact grazing by carp and turtles appeared to have on initial establishment, development of new colonies was not anticipated.

Figure 16. American pondweed colonies in Cooper Lake, July 2000

However, at some point, some critical rate of propagule production must have exceeded rates of grazing and resulted in new colony formation from founder colony fragments and seeds.

Studies continue to be conducted in Cooper Lake to refine protective exclosures and monitor the success of protecting founder colonies by chasing water levels over a longer period. Additionally, the project continues to monitor persistence of new colonies and establishment of colonies in other parts of the lake.

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14. ABSTRACT
Aquatic plants improve water clarity and quality (James and Barko 1990) and reduce rates of shoreline erosion and sediment resuspension (James and Barko 1995). Further, aquatic plants provide valuable fish and wildlife habitat (Dibble et al. 1996) and serve as a food source for waterfowl and aquatic mammals. Native aquatic plants also help prevent spread of nuisance exotic plants (Smart et al. 1994), a role that has been of primary interest to the Aquatic Plant Control Research Program (APCRP).

Because the research on aquatic plant establishment conducted under the APCRP represented the current "state of the art" (Smart et al. 1996), the Texas Parks and Wildlife Department solicited our involvement in the development of techniques (TPWD Aquatic Habitat Enhancement Initiative) for establishing aquatic plants for fish habitat improvement in Texas reservoirs. Because there is still much to learn regarding establishment of beneficial native plants, we elected to participate in this project and to incorporate testing and data collection in an attempt to further advance the science. This report documents the restoration project and describes what we learned in the process.

15. SUBJECT TERMS
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